Lecture 5. Concrete

Prepared by:
Fahim Al-Neshawy, D.Sc. (Tech.)
Aalto University School of Engineering
Department of Civil Engineering
A: P.O.Box 12100, FIN-00076 Aalto, Finland
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5.1 Basic ingredients of concrete

Concrete is a mixture of cement, water, fine aggregate (sand) and coarse aggregate (gravel or crushed rocks) in which the cement and water have hardened by a chemical reaction – hydration – to bind the nearly (non-reacting) aggregate.

![Diagram of concrete ingredients](image)

The importance of the ingredients should be known before they are used in cement concrete.

5.1.1 Cement

Cement is the binding material in the cement concrete. This concrete is used for different engineering works where strength and durability are of prime importance.

**Functions of cement:**

- It fills up voids existing in the fine aggregate and makes the concrete impermeable.
- It provides strength to concrete on setting and hardening.
- It binds the aggregate into a solid mass by virtue of its setting and hardening properties when mixed with water.

5.1.2 Aggregate

Aggregates are used in two size groups to provide good quality of concrete:

- Fine aggregate (sand) particle size less than 4.75mm
- Coarse aggregate – Particle size more than 4.75mm
Fine aggregate (sand):
Sand consists of small angular or rounded grains of silica. Sand is commonly used as the fine aggregate in cement concrete. Both natural and artificial sands are used for this purpose.

Functions of sand:
1. It fills the voids existing in the coarse aggregate.
2. It reduces shrinkage and cracking of concrete.
3. By varying the proportion of sand concrete can be prepared economically for any required strength.
4. It helps in hardening of cement by allowing the water through its voids.
5. To form hard mass of silicates as it is believed that some chemical reaction takes place between silica of sand and constituents of cement.

Requirements:
1. Fine aggregate should consist of coarse angular sharp and hard grains.
2. It must be free from coatings of clay and silt.
3. It should not contain any organic matter.
4. It should be free from hygroscopic salt.
5. It should be strong and durable and chemical inert.
6. The size of sand grains should pass through 4.75mm sieve and should be entirely retained on 75 micron sieve.

Coarse aggregate:

Functions of coarse aggregates:
1. Coarse aggregate makes solid and hard mass of concrete with cement and sand.
2. It increases the crushing strength of concrete.
3. It reduces the cost of concrete, since it occupies major volume.

Requirements:
1. Coarse aggregate used may be crushed stone, gravel and broken bricks.
2. Crushed stone: It is an excellent coarse aggregate provided. It is obtained by crushing granite, sandstone and close grained limestone.
3. Crushed granite chips are commonly and advantageously used in reinforced cement concrete.
4. Broken bricks well burnt and over burnt bricks are broken into suitable size and used as aggregate. It should be well watered before its use. Broken bricks are used as aggregate for concrete in foundations and under floors.
5. But generally crushed stone is only used as coarse aggregate.
5.1.3 Water

The water is used in concrete plays an important part in the mixing, laying compaction setting and hardening of concrete. The strength of concrete directly depends on the quantity and quality of water is used in the mix.

Functions of water:

1. Water is only the ingredient that reacts chemically with cement and thus setting and hardening takes place.
2. Water acts as a lubricant for the aggregate and makes the concrete workable.
3. It facilitates the spreading of cement over the fine aggregate.

5.1.4 Concrete admixtures

Concrete admixtures are added to change the properties of concrete to make it function as required. Admixtures are used to modify properties of both fresh and hardened concrete as discussed below:

Functions of admixtures to modify fresh concrete properties:

a) To increase workability without increasing water content or to decrease the water content at the same workability.
b) To retard or accelerate both initial and final setting times.
c) To reduce or prevent settlement.
d) To create slight expansion in concrete and mortar.
e) To modify the rate or capacity for bleeding or both.
f) To reduce segregation of concrete, mortars and grouts.
g) To improve penetration and or pumpability of concrete, mortars and grouts.
h) To reduce rate of slump loss.

Functions of admixtures to modify hardened concrete properties:

a) To retard or reduce heat generation during early hardening.
b) To accelerate the rate of strength development.
c) To increase the strength of concrete or mortar (Compressive, tensile or flexural).
d) To increase the durability or resistance to severe conditions of exposure including the application de-icing salts.
e) To decrease the capillary flow of water.
f) To decrease the permeability to liquids.
g) To control the expansion caused by the reaction of alkalis with certain aggregate constituents.
h) To produce cellular concrete.
i) To increase the bond of concrete to steel reinforcement.
j) To increase the bond between old and new concrete.
k) To improve impact resistance and abrasion resistance.
l) To inhibit the corrosion of embedded metal.
m) To produce coloured concrete or mortar.

The classification of concrete admixtures is presented as follow:

1. **Set-Retarding:**
Set retarding concrete admixtures are used to delay the chemical reaction that takes place when the concrete starts the setting process.

2. **Air-Entrainment:**
Air entrained concrete can increase the freeze-thaw durability of concrete. Other benefits from this admixture are:
   - High resistance to cycles of wetting and drying
   - High degree of workability
   - High degree of durability

The entrained air bubbles act as a physical buffer against the cracking caused by the stresses due to water volume augmentation in freezing temperatures. Air entrainers are compatible with almost all the concrete admixtures. Typically for every 1% of entrained air, compressive strength will be reduced by about 5%.

3. **Water-Reducing:**
Water-reducing admixtures are chemical products that when added to concrete can create a desired slump at a lower water cement ration than what is normally designed. Water-reducing admixtures are used to obtain specific concrete strength using lower cement content.

4. **Accelerating:**
Accelerating concrete admixtures are used to increase the rate of concrete strength development, or to reduce concrete setting time. Calcium chloride could be names as the most common accelerator component; however, it could promote corrosion activity of steel reinforcement. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

5. **Shrinkage Reducing:**
Shrinkage reducing concrete admixtures are added to concrete during initial mixing. This type of admixture could reduce early and long term drying shrinkage.

6. **Super plasticizers:**
The main purpose of using super plasticizers is to produce flowing concrete with very high slump in the range of 200 - 250 mm to be used in heavily reinforced structures and in placements where adequate consolidation by vibration cannot be readily achieved. The other major application is the production of high-strength concrete at w/c's ranging from 0.3 to 0.4. High workability concrete
containing super plasticizer can be made with a high freeze-thaw resistance, but air content must be increased relative to concrete without super plasticizer.

7. Corrosion-Inhibiting:

Corrosion-inhibiting admixtures fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can significantly reduce maintenance costs of reinforced concrete structures throughout a typical service life of 30 – 40 years.

5.2 Concrete mix design procedure (Nykänen method)

Mix design is the process of selecting the proportions of cement, water, fine and coarse aggregates and, if they are to be used, additions and admixtures to produce an economical concrete mix with the required fresh and hardened properties.

Nykänen method (1):

- Developed by professor Arvo Nykänen (1912 – 1990)
- 1\textsuperscript{st} version of the proportion method was developed in 1945 and the publications about the method during the years 1947 and 1948
- The new version of the methods established in 1955 because of the changes in the code of practices and the development of concrete technology

5.2.1 Specified concrete properties

A properly proportioned concrete mix should possess the following qualities:

i. Acceptable workability of the freshly mixed concrete
ii. Durability, strength, and uniform appearance of the hardened concrete \(\dagger\) result from the structural design process
iii. Economy.

The requirement (input) for the Nykänen method are:

- The 28 days compressive strength of the concrete (nominal strength)
- The slump of the fresh concrete mass (workability), shown in Table 1.
- The 28 days compressive strength of the cement used
- The air-content of concrete (\textit{generally assumed 2% for normal concrete})
- The grading and the moisture content of the aggregates
- The amount of absorbing water in the aggregates (\textit{generally estimated to be 0.4 %})
- Any other information about the concrete structure

Table 1. The permissible slump for various types of concrete in relation to their use²

<table>
<thead>
<tr>
<th>Concrete structures</th>
<th>Consistency (Slump), [mm]</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced foundation walls and footings</td>
<td></td>
<td>125</td>
<td>50</td>
</tr>
<tr>
<td>Plain footings, caissons and substructure walls</td>
<td></td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Slabs, beams, thin reinforced walls and building columns</td>
<td></td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>Pavements and floor laid on ground</td>
<td></td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Heavy mass construction</td>
<td></td>
<td>75</td>
<td>25</td>
</tr>
</tbody>
</table>

5.2.2 Procedure for concrete mix design

**MIX DESIGN EXERCISE:**

Proportion a concrete mix with a 28 day compressive strength of 35 MPa and a slump of 90 mm, made with ordinary Portland cement with cement strength of 49.5 MPa. Grading of the aggregate is presented in Figure 4. All aggregates are dry, absorbing 0.8%, not crushed.

**Step 1. Calculating the proportioning strength:**

The proportion strength is calculated using the following equation:

\[ K_s = k_t \times K \times k_{cem} = 1.2 \times 35 \times \frac{42.5}{49.5} = 36 \text{ MPa} \]  

(1)

Where:

- \( K_s \): proportion strength for the concrete mix
- \( k_t \): target strength factor, \( k_t = 1.2 \)
- \( K \): nominal strength of the concrete (28d compressive strength)
- \( k_{cem} \): cement strength factor  
  \((k_{cem} = \frac{42.5}{N})\), where \( N \) is the 28d cement strength in MPa, according to Nykänen proportioning formula

**Step 2. Choice of the aggregates and calculating of the grading factor (H)**

Selecting the maximum coarse aggregate size: The maximum size of coarse aggregate that can be used in a mix depends on the size, shape, and reinforcing of a concrete member.

Maximum aggregate size \( (D_{\text{max}}) \) should **not be larger than:**

i) 1/5 the minimum dimension of structural members such as beams, columns, frames etc. (B),

ii) 1/3 the thickness of a concrete slab, or

iii) 3/4 the clearance between reinforcing rods (S)

iv) 3/4 the concrete cover depth (C) + the clearance between reinforcing steel and the concreting forms (molds).

These restrictions limit maximum aggregate size to 32 mm, except in mass applications. In many areas, the largest available sizes are 16 mm. to 32 mm\(^3\). **For the laboratory concrete mix design, the maximum aggregate size is the sieve size that passes 95% of the combined aggregate.**

Specify the guideline passing values for sieve #0,125 mm and sieve #4 mm aggregates from the mix design form based on (1) the proportion strength \( K_s \) and (2) the maximum aggregate (see Figure 4).

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\(^3\)ACI 211.1: Maximum Aggregate Size For Concrete Mix Design. Online at:  
http://www.ce.memphis.edu/1112/notes/project_2/beam/ACI_mix_design.pdf
Selecting of the guideline passing values for #0.125 mm and #4 mm aggregates.

**Example:**

**Input:**
- $K_s = 36$ MPa
- Max. size = 32 mm

**Output:**
- $< 0.125$ mm $= 4\%$
- $< 4$ mm $= 37\%$

**MIX DESIGN EXERCISE:**

Based on the values from Figure 2, we generate groups of equations (based on the number of aggregate fractions) in order to solve the %-values for the aggregates. In this example we consider only three fractions, shown in Figure 4, to be solved manually using (iteration method in Excel for example).

\[
\begin{align*}
< \# 0.125 \text{ mm} & \quad a \cdot 12 + b \cdot 3 + c \cdot 0 \approx 4\% \\
< \# 4 \text{ mm} & \quad a \cdot 100 + b \cdot 30 + c \cdot 5 \approx 37\% \\
\text{Combined} & \quad a + b + c \approx 100\%
\end{align*}
\]
After a few iteration steps for the first and second equation, we got the following values: (a = 27%, b = 25% and c = 48%). Notice that you can’t find the exact values for a, b and c, but make them close enough.

The steps for the choice of the aggregates as follow (example using Excel sheet is shown in Figure 4):

1) Using the aggregate grading available
2) Calculate the passing percentages for each aggregate fraction based on (i) the cumulative passing through 0.125 and 4 mm and (ii) fitting the aggregate limits curve
3) Calculate the granulometric value of the grading factor (H) using (2).

\[
H = \sum_{\text{sand}} \left( \frac{\text{Fraction portion} \times (\%)}{100} \right) \times \sum_{0.125} \text{Sieve passing value} \times (\%)
\]
Upper and lower limits for the aggregate size distribution based on the maximum aggregate size

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>0.125</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>16</th>
<th>32</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>32# Upper limit</td>
<td>6</td>
<td>13</td>
<td>21.1</td>
<td>30</td>
<td>41</td>
<td>55</td>
<td>72.5</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>32# Lower limit</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>17</td>
<td>25</td>
<td>37</td>
<td>52</td>
<td>72.2</td>
<td>100</td>
</tr>
<tr>
<td>16# Upper limit</td>
<td>6</td>
<td>14</td>
<td>22.5</td>
<td>38</td>
<td>52</td>
<td>72</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>16# Lower limit</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>15</td>
<td>22</td>
<td>35</td>
<td>50</td>
<td>70</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Figure 4.** Example of aggregate combination procedure and calculating the grading factor (H).

### Step 3. Specifying the amounts of water, cement and aggregates

Using the mix design form shown in Figure 5 to specify the amounts of water, cement and aggregates is following the next procedure:

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Amounts</th>
<th>Grading</th>
<th>Grading factor H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a Sand</td>
<td>12</td>
<td>20</td>
<td>72</td>
</tr>
<tr>
<td>b Gravel</td>
<td>3</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>c Rough gravel</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Combination</td>
<td>27</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Combination</td>
<td>25</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Combination</td>
<td>48</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Mix design Exercise**

- Ks = 36 MPa
- Slump = 90 mm
- No crushed aggregates (0%)
- Air content 2% (20 dm³ of air in m³ concrete)
- The grading factor, H = 412
Figure 5. Concrete mix design - Specifying the amounts of water, cement and aggregates

1) Using the grading factor (H) value, point (1)
2) Move vertically to the value of the concrete slump (input - workability), point (2)
3) Move horizontally (consider the amount of crushed aggregates, which was 0% in the example case) to point (3)
4) Move parallel with the same slope as the proportional strength $K_s$ line until the meet the $K_s$ value, point (4)
5) Move horizontally (consider the air content, which was 2% in the example case) to point (5). Notice: if the air content is more than 2%, 1st you move horizontally, then parallel to the air content lines to point (5)
6) Connect point (5) with point (6), which is the value of the proportional strength $K_s$ using straight line
7) Point (7) is the amount of water + air (dm³/m³-concrete). Because you know already the air content (A), you be able to calculate the amount of water (W)
8) Point (8) is the amount of aggregates (kg/m³) or (dm³/m³). Remember to take into account the effective amount of water (effective amount of water = total water - absorbed water) when calculating the final aggregate mix.

9) Point (9) is the amount of cement (kg/m³) or (dm³/m³)

**MIX DESIGN EXERCISE:**

Water + Air = 188 dm³/m³  ‍ ‍ ‍ ‍ ‍ ‍ ‍ ‍ point (7)

Air = 20 dm³

Water = 188 – 20 = 168 dm³ = 168 kg/m³ - concrete (density of water 1 kg/dm³)

Aggregates = 1860 kg/m³ - concrete  ‍ ‍ ‍ ‍ ‍ ‍ ‍ ‍ point (8)

Cement = 310 kg/m³ - concrete  ‍ ‍ ‍ ‍ ‍ ‍ ‍ ‍ point (9)

All aggregates are dry (i.e moisture content 0%), absorbed water 0.8 %, not crushed

**Step 4. Adjustments for aggregate moisture and final proportion**

**Aggregate weights:**

Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

**Amount of mixing water:**

If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Example of the aggregates and mixing water adjustments is shown in Table 2.

**Table 2. Concrete mix proportion with adjustment.**

<table>
<thead>
<tr>
<th>Concrete ingredient</th>
<th>Amount, kg/m³</th>
<th>Aggregate fraction</th>
<th>Fraction portion (%)</th>
<th>Mix (kg/m³)</th>
<th>Water content of aggregates</th>
<th>Adjusted mix (kg/m³)</th>
<th>BATCH  _ _ _ _m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>310</td>
<td></td>
<td></td>
<td>310</td>
<td></td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>Aggregates</td>
<td>1860</td>
<td>Sand</td>
<td>27</td>
<td>502</td>
<td>0</td>
<td>0.8 -0.8 -4.0</td>
<td>498</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel</td>
<td>25</td>
<td>465</td>
<td>0</td>
<td>0.8 -0.8 -3.7</td>
<td>461</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rough gravel</td>
<td>48</td>
<td>893</td>
<td>0</td>
<td>0.8 -0.8 -7.1</td>
<td>886</td>
</tr>
<tr>
<td>Water</td>
<td>168</td>
<td></td>
<td></td>
<td>168</td>
<td></td>
<td>183</td>
<td></td>
</tr>
<tr>
<td>Air content  (4)</td>
<td>[20]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[20]</td>
</tr>
</tbody>
</table>

(1) Free water = (total - absorbed) (%)

(2) Free water (kg/m³) = (Free water (%) * amount of aggregate fraction (kg/m³)) / 100

(3) Adjusted aggregate fraction value = value of aggregate fraction (kg/m³) + Free water (kg/m³)

Adjusted water value = Water content (kg/m³) - total amount of free water (kg/m³)

(4) The target volume of the air in the concrete mix (dm³/m³)
5.3 Batching and mixing of concrete

The proper batching, mixing, and handling of fresh concrete are important prerequisites for strong and durable concrete structures. There are several steps and precautions that must be followed in mixing and handling fresh concrete in order to ensure a quality material with the desired characteristics.

5.3.1 Batching of concrete ingredients

Batching is measuring and introducing the concrete ingredients into the mixer:

- **Batching by volume:**
  - This method is generally adopted for small jobs.
  - Gauge boxes are used for measuring the fine and coarse aggregate.

- **Batching by Weight:**
  - Batching by weight is more preferable to volume batching, as it is more accurate and leads to more uniform proportioning.
  - It does not have uncertainties associated with bulking.
  - Batching by weight equipment falls into 3 general categories:
    1) Manual: batching of concrete are done manually and it is used for small jobs.
    2) Semi-automatic: the aggregate bin gates are opened by manually operated switches and are closed automatically when the material has been delivered. This system also contains interlock which prevents charging and discharging.
    3) Fully automatic: the materials are weighted automatically | Ready mixed plants.

5.3.2 Concrete mixers

Concrete should be mixed thoroughly, either in a mixer or by hand, until it becomes uniform in appearance.

- Hand mixing is usually limited to small jobs or situations in which mechanical mixers are not available.
- Mechanical mixers include on-site mixers and central mixers in ready-mix plants.
- The capacity of these mixers varies from 1.5 m$^3$ to 9 m$^3$.
- Most of the mixers are batch mixers, although some mixers are continuous.
- Batch mixers are pan mixers and drum mixers
- Drum mixers vary in type, such as tilting, non-tilting, and reversing-type mixers.
5.3.3 Mixing of concrete

- Mixing time and number of revolutions vary with the size and type of the mixer.
- Specifications usually require a minimum of 1 minute of mixing for stationary mixers of up to 0.75 m³ of capacity, with an increase of 15 seconds for each additional 0.75 m³ of capacity.
- Mixers are usually charged with 10% of the water, followed by uniform additions of solids and 80% of the water. Finally, the remainder of the water is added to the mixer.

The loading method includes the order of loading the constituents into the mixer and also the duration of the loading period. The duration of this period depends on how long the constituents are mixed dry before the addition of water and how fast the constituents are loaded. The loading period is extended from the time when the first constituent is introduced in the mixer to when all the constituents are in the mixer. The **loading period** is divided into two parts:

1) **dry mixing:**
   
   occurs during loading but before water is introduced

2) **wet mixing**

   Wet mixing is the mixing after or while water is being introduced, but still during loading.

The **mixing period** is defined as the time between the loading of all constituents and the beginning of concrete discharge (see Figure 7).

The **discharge** from the mixer should be arranged so that it increases productivity (fast discharge), and it does not modify (slow discharge) the homogeneity of the concrete.
5.3.4 Ready-Mixed Concrete (RMC)

Ready-mixed concrete is mixed in a central plant, and delivered to the job site in mixing trucks ready for placing (Figure 8).

- Ready Mix Concrete is a technique of production of concrete in massive quantities away from the actual site of placing.
- It is very useful where demand of concrete is very high and construction sites are in blocked areas, where mixing on site is not possible due to lack of storage place.
- RMC is ready to use material. It is widely adopted throughout the world.
- It reduces noise pollution as well as air pollution.
- The supervisory and labour costs associated with the production of RMC is less, and the quality of concrete is high.
- It is suitable for huge industrial and residential projects where time plays a vital role.
- So ultimately it provides economy in the construction and better finish to the structure.

Three mixing methods can be used for ready-mixed concrete:

1. Central-mixed concrete is mixed completely in a stationary mixer and delivered in an agitator truck (2 rpm to 6 rpm).
2. Shrink-mixed concrete is partially mixed in a stationary mixer and completed in a mixer truck (4 rpm to 16 rpm).
3. Truck-mixed concrete is mixed completely in a mixer truck (4 rpm to 16 rpm).
Figure 8. Schematic view of a ready mix plant
5.4 Properties of fresh concrete

There are two sets of criteria that we must consider when making concrete:

1. Short-term requirements, like workability
2. Long-term requirements of hardened concrete, such as, strength, durability, and volume stability

5.4.1 Workability

ACI (American Concrete Institute) defines the concrete workability as 'that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished'.

A concrete is said to be workable if:

- It can be handled without segregation
- It can be placed without loss of homogeneity
- It can be compacted with specified effort
- It can be finished easily

Depending upon the water cement ratio in the concrete mix, the workability may be determined by the following three methods: (i) Slump Test, (ii) Compaction Factor Test, (iii) Vee-bee Consistometer test. The workability is a composite property, with at least two main components:

   a. **Consistency**: which is described as the “ease of flow” of the concrete, and
   b. **Cohesiveness**: which he describes as the “tendency not to bleed or segregate”

This lecture will cover the slump test. For more reading about the other test see for example the following link: [http://civilblog.org/2015/10/29/3-methods-of-determining-workability-of-concrete/](http://civilblog.org/2015/10/29/3-methods-of-determining-workability-of-concrete/)

5.4.1.1 Factor affecting the workability

The factors which affect workability of concrete are:

- **Cement content of concrete**: More the quantity of cement, the more will be the paste available to coat the surface of aggregates and fill the voids between them will help to reduce the friction between aggregates and smooth movement of aggregates during mixing, transporting, placing and compacting of concrete
- **Water content of concrete**: Generally, a water cement ratio of 0.45 to 0.6 is used for good workable concrete without the use of any admixture.
- **Mix proportions of concrete**: the low cement - aggregate ratio of concrete will make the less paste available for aggregates and mobility of aggregates is restrained.

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4 [http://www.ce.memphis.edu/1101/notes/concrete/everything_about_concrete/08_fresh.html](http://www.ce.memphis.edu/1101/notes/concrete/everything_about_concrete/08_fresh.html)
- **Size of aggregates:** Lower sizes of aggregates with same water content are less workable than the large size aggregates.
- **Shape of aggregates:** Rounded aggregates will be easy to mix than elongated, angular and flaky aggregates due to less frictional resistance.
- **Use of admixtures in concrete:** Workability enhancer admixtures such as plasticizers and super plasticizers which increases the workability of concrete even with low water/cement ratio.

### 5.4.1.2 Consistency (Slump) test

Workability (Consistency) of concrete mixture is measured by **slump test**, EN 12350-2 - Testing fresh concrete. Slump test \(^{(5)}\). Slump test, shown in Figure 9, is carried out with a mould called slump cone whose top diameter is 10 cm, bottom diameter is 20 cm and height is 30 cm. The test may be performed in the following steps:

1. Place the slump mould on a smooth flat and non-absorbent surface.
2. Place the mixed concrete in the mould to about one-fourth of its height.
3. Compact the concrete 25 times with the help of a tamping rod uniformly all over the area.
4. Place the concrete in the mould about half of its height and compact it again.
5. Place the concrete up to its three fourth height and then up to its top. Compact each layer 25 times with the help of tamping rod uniformly. For the second subsequent layers, the tamping rod should penetrate into underlying layers.
6. Strike off the top surface of mould with a trowel or tamping rod so that the mould is filled to its top.
7. Remove the mould immediately, ensuring its movement in vertical direction.
8. When the settlement of concrete stops, measure the subsidence of the concrete in millimetres which is the required slump of the concrete.

![Figure 9. Measurement of the concrete slump (Slump Test)](http://theconstructor.org/practical-guide/workability-site-test-recommended-values/5150/)
The standards for slump defines three conditions where the slump test should not be used, see .

1) **Non-plastic concrete (Zero Slump):** When slump is less than 15 mm, concrete may not be adequately plastic for the slump test. The slump test is not effective in distinguishing these concrete mixtures: two concretes with a zero slump can have drastically different workability, especially in their response to vibration.

2) **Non-cohesive concrete (Collapsed slump):** When slump is greater than 230 mm, concrete may not be adequately cohesive for the slump test. Non-cohesive concrete is highly susceptible to segregation and should be redesigned, such as by adding a viscosity modifying admixture or adjusting aggregate grading. Not all concrete with slump greater than 230 mm is non-cohesive. For example, self-consolidating concrete can flow under its own mass with adequate cohesion to resist segregation.

3) **Shear slump concrete:** If during the slump test, a portion of the concrete shears from the rest of the concrete, the slump cannot be evaluated.

![Figure 10. Concrete slump conditions.](image)

**Applications of slump test**

- The slump test is used to ensure uniformity for different batches of similar concrete under field conditions and to ascertain the effects of plasticizers on their introduction.
- This test is very useful on site as a check on the day-to-day or hour-to-hour variation in the materials being fed into the mixer. An increase in slump may mean, for instance, that the moisture content of aggregate has unexpectedly increases.
- Other cause would be a change in the grading of the aggregate, such as a deficiency of sand.
- Too high or too low a slump gives immediate warning and enables the mixer operator to remedy the situation.
### Table 3. Concrete slump for various uses.

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Slump [mm]</th>
<th>Use</th>
<th>Method of compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>High workability</td>
<td>100 - 150</td>
<td>Constructions with narrow passages and/or complex shapes. Heavily reinforced concrete.</td>
<td>Manual</td>
</tr>
<tr>
<td>Medium workability</td>
<td>50 - 100</td>
<td>All normal uses. Non-reinforced and normally reinforced concrete.</td>
<td>Manual</td>
</tr>
<tr>
<td>Plastic</td>
<td>25 - 50</td>
<td>Open structures with fairly open reinforcement, which are heavily worked manually for compaction like floors and pavings. Mass concrete.</td>
<td>Manual or Mechanical</td>
</tr>
<tr>
<td>Stiff</td>
<td>0 - 25</td>
<td>Non-reinforced or sparsely reinforced open structures like floors and pavings which are mechanically vibrated. Factory pre-fabrication of concrete goods. Concrete blocks.</td>
<td>Mechanical</td>
</tr>
<tr>
<td>Damp</td>
<td>0</td>
<td>Factory prefabrication of the concrete goods.</td>
<td>Mechanical or Pressure</td>
</tr>
</tbody>
</table>

#### 5.4.1.3 Segregation and Bleeding

![Figure 11. Segregation of concrete.](image)

**Segregation** refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. This can be seen as a separation of coarse aggregate from the mortar, caused from either the settling of heavy aggregate to the bottom or the separation of the aggregate from the mix due to improper placement.

Some factors that increase segregation are:

- Larger maximum particle size (25mm) and proportion of the larger particles.
- High specific gravity of coarse aggregate.
- Decrease in the amount of fine particles.
- Particle shape and texture.
- Water/cement ratio.

Good handling and placement techniques are most important in prevention of segregation.
Bleeding is defined as the appearance of water on the surface of concrete after it has consolidated but before it is set. Since mixing water is the lightest component of the concrete, this is a special form of segregation. Bleeding is generally the result of aggregates settling into the mix and releasing their mixing water. Some bleeding is normal for good concrete.

However, if bleeding becomes too localized, channels will form resulting in "craters". The upper layers will become too rich in cement with a high w/c ratio causing a weak, porous structure. Salt may crystalize on the surface which will affect bonding with additional lifts of concrete. This formation should always be removed by brushing and washing the surface. Also, water pockets may form under large aggregates and reinforcing bars reducing the bond.

Bleeding may be reduced by:

- Increasing cement fineness.
- Increasing the rate of hydration.
- Using air-entraining admixtures.
- Reducing the water content.
5.4.2 Setting time of concrete

Setting is defined as the onset of rigidity in fresh concrete. Hardening is the development of usable and measurable strength; setting precedes hardening. Both are gradual changes controlled by hydration.

Fresh concrete will lose measurable slump before initial set and measurable strength will be achieved after final set.

Setting is controlled by the hydration of $C_3S$. The period of good workability is during the dormant period, (stage 2). Initial set corresponds to the beginning of stage 3, a period of rapid hydration. Final set is the midpoint of this acceleration phase. A rapid increase in temperature is associated with stage 3 hydration, with a maximum rate at final set.

If large amounts of ettringite rapidly form from $C_3A$ hydration, the setting times will be reduced. Cements with high percentages of $C_3A$, such as expansive or set-regulated cements, are entirely controlled by ettringite formation.

![Figure 13. Stages in the hydration of cement.](image-url)
The concrete setting time at various temperatures is given at Table 4 below:

Table 4. Setting time of concrete at various temperature.

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Approximate Setting Time [hours]</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>0.66 to 1</td>
</tr>
<tr>
<td>32</td>
<td>0.66 to 2</td>
</tr>
<tr>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>-1</td>
<td>19</td>
</tr>
<tr>
<td>-7</td>
<td>Set will not occur</td>
</tr>
</tbody>
</table>

5.4.3 Air content

The main reason for entraining air in concrete is to control damage from freeze thaw cycles. Air tests determine the total content of entrained and entrapped air in concrete. During batching and mixing tiny air bubbles are created in the concrete mix. If the concrete contains an air-entraining admixture, these bubbles remain stabilized in the mix due to the electrostatic binding of air, water and cement. In concrete without air entrainment, all but about 2% of the air content escapes or dissolves after consolidation because the bubbles are not bonded to the water and cement. The remaining air is called "entrapped" air. Entrapped air will not aid in preventing freeze thaw damage.

The methods for measuring total air content (entrapped and entrained) of concrete are:

- Pressure Method
- Volumetric Method
- Gravimetric Method
- Chase Air Indicator

The pressure method is used for mixes containing normal to heavy-weight aggregate.
The pressure method test procedure:

1. The test should begin within 15 minutes after obtaining the composite sample.
2. Start by filling the 8 liter base of the air-content test device in three equal layers, and rod each layer 25 times. After rodding, strike the outside of the base with a mallet 12 to 15 times to close any air voids.
3. After completing the three equal layers, strike off the bowl flush at the top to completely fill the 8 liter volume.
4. At this point, it can be weighed as part of the calculation to determine the fresh concrete unit weight (density of fresh concrete).
5. Next, latch the top of the air-content test device over the base and fill the air gap between the top of the struck-off concrete and the underside of the top of air meter with water.
6. The meter top is then pressurized with the built-in hand pump until zeroed out.
7. After a stabilization period, release the pressure in the top and read the air-void content on the dial on the top of the meter.
8. Subtract the aggregate correction factor from the dial reading and report the final value.

Testing tip: Aggregate correction factor = reading on gage - % of air removed. The % of air removed is the amount of water removed from meter into the calibration vessel.

5.5 Properties of hardened concrete

Fully cured, hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strongest and durable building material. The properties of hardened concrete are: Strength, Creep, Durability, Shrinkage, Modulus of Elasticity and Water tightness (impermeability).

5.5.1 Strength of concrete

When we refer to concrete strength, we generally talk about compressive strength of concrete. Because, concrete is strong in compression but relatively weak in tension and bending. Concrete compressive strength is measured in (MPa). Compressive strength mostly depends upon amount and type of cement used in concrete mix. It is also affected by the water-cement ratio, mixing method,

placing and curing. Concrete tensile strength ranges from 7% to 12% of compressive strength. Both tensile strength and bending strength can be increased by adding reinforcement.

![Graph showing strength gain of concrete with age](image)

*Figure 15. Strength gaining of concrete with age*[^7].

### 5.5.2 Creep of concrete

Creep of concrete is the continued deformation with time under applied load. The rate of creep decrease with time and the creep strains at five years are taken as terminal values. Creep increases rapidly with the stress, loading at an early age of concrete, broken ballast, soft and porous aggregate, poorly graded and improperly compacted concrete. The deformation of hardened concrete is shown in Figure 16. The Causes of Creep are:

- Closer of internal voids of concrete
- Viscous flow of the cement paste inside concrete
- Flow of water out of the cement gel inside concrete.

5.5.3 Durability of concrete

Durability might be defined as the ability to maintain satisfactory performance over and extended service life. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years. Most concrete buildings are demolished due to obsolescence rather than deterioration.

Different concretes require different degrees of durability depending on the exposure environment and properties desired. Appropriate concrete ingredients, mix proportions, finishes and curing practices can be adjusted on the basis of required durability of concrete.

5.5.4 Shrinkage in Concrete

Concrete is subjected to changes in volume either autogenous or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. Shrinkage can be classified in the following way:

a) Plastic Shrinkage: Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade, is believed to be the reasons of plastic shrinkage.

b) Drying Shrinkage

c) Autogeneous Shrinkage: In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage. Autogeneous
shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam

d) **Carbonation Shrinkage:** Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.

### 5.5.5 Modulus of Elasticity

The modulus of Elasticity of concrete depends on the Modulus of Elasticity of the concrete ingredients and their mix proportions. The value of the concrete could be predicted based on the compressive strength of concrete. The values modulus of elasticity are derived from the following equation.

\[
E_{c28} = K_0 + 0.2f_{cu, 28}
\]

where:

- \(E_{c28}\) = static modulus of elasticity at 28 days, GPa
- \(f_{cu, 28}\) = characteristic cube strength, MPa
- \(K_0\) = a constant closely related to the modulus of elasticity of the aggregate (taken as 20 kN/mm² for normal-density concrete)

### 5.5.6 Water tightness (impermeability) of concrete

If concrete is impermeable, corrosive agents cannot penetrate and attack it. Concrete basically has two types of pores, which determine permeability. These are capillary pores (with a diameter varying between 0.01 to 10 micron) in the cement, paste which coats the aggregates and larger micro voids, between 1 mm to 10 mm, which are caused by faulty compaction of fresh concrete.

When voids are interconnected because of their larger number and size a continuous link is formed, which makes the concrete permeable.

There are three major factors which determine the permeability in concrete.

- a. Water cement ration,
- b. Compaction and
- c. Curing.

Each factor is equally important, if one of these factors is not controlled, the result will be increase, in permeability of the concrete. It can be shown that permeability increases as water cement ratio increase. Typically, at a water cement ratio of around 0.4, permeability is practically zero.
5.6 Advantages and disadvantages of reinforced concrete

Reinforced concrete is a combination of traditional cement concrete with reinforcements (steel bar). This combination is made to utilize the compressive strength of concrete and tensile strength of steel simultaneously. In reinforced concrete, the components work together to resist many types of loading. Concrete resists compression and steel reinforcement resists tension forces. Reinforced concrete, as an economic building material, is very popular now-a-days. It is widely used in many types building around the world. Along with many advantages reinforced concrete also poses some disadvantages also.

Advantages of Reinforced Concrete

- Reinforced concrete has a high compressive strength compared to other building materials.
- Due to the provided reinforcement, reinforced concrete can also withstand a good amount of tensile stress.
- Fire and weather resistance of reinforced concrete is fair.
- The reinforced concrete building system is more durable than any other building system.
- Reinforced concrete, as a fluid material in the beginning, can be economically moulded into a nearly limitless range of shapes.
- The maintenance cost of reinforced concrete is very low.
- In structure like footings, dams, piers etc. reinforced concrete is the most economical construction material.
- It acts like a rigid member with minimum deflection.
- As reinforced concrete can be moulded to any shape required, it is widely used in precast structural components. It yields rigid members with minimum apparent deflection.
- Compared to the use of steel in structure, reinforced concrete requires less skilled labour for the erection of structure.
Disadvantages of Reinforced Concrete

- The tensile strength of reinforced concrete is about one-tenth of its compressive strength.
- The main steps of using reinforced concrete are mixing, casting, and curing. All of this affect the final strength.
- The cost of the forms used for casting reinforced concrete is relatively higher.
- For multi-storied building the reinforced concrete column section for is larger than steel section as the compressive strength is lower in the case of reinforced concrete.
- Shrinkage causes crack development and strength loss.